2018 DOE Vehicle Technologies Office Annual Merit Review Oral Presentation: Technology Integration

Advanced Vehicle Technology Competitions -- EcoCAR

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Argonne National Laboratory

June 19, 2018

Sponsored by Connie Bezanson

Project ID: ti070

Overview

Timeline

- Project Start Date July 2012
  - OEM RFP released: July 2012
  - OEM selected: Dec 2012
  - Univ. RFP released: April 2013
  - Universities selected: March 2014
  - Launch Workshop: April 2014
  - Year 1: August 2014 – June 2015
  - Year 2: August 2015 – June 2016
  - **Years 3: August 2016 – June 2017**
  - Year 4: August 2017 – June 2018
- Project End Date June 2018
- Percent Complete 98%

Barriers

- **A.** Lack of trained engineers and scientists
- **B.** Lack of advanced vehicle technology curricula
  - Improving cross disciplinary collaboration at university administration level
  - Improving curriculum availability for automotive engineering education, model based design and validation methodologies
- **C.** Showcase advanced technology vehicles that exemplify the ingenuity and innovation of future leaders

Partners

- DOE, General Motors
- 30 other government & industry sponsors
- 16 Universities
- Project Lead: Argonne National Laboratory

Budget*

Fiscal Year	DOE	GM	Other Sponsors	TOTAL
2018	$2,300,000	$6M	$1.9M	$16,710,884
2017	**$2,294,000**			
2016	$3,296,518			
2015	$2,490,249			

**Does not include $88M of in-kind/cash support provided to universities or in-kind to competition*

Project Objectives

Objectives:

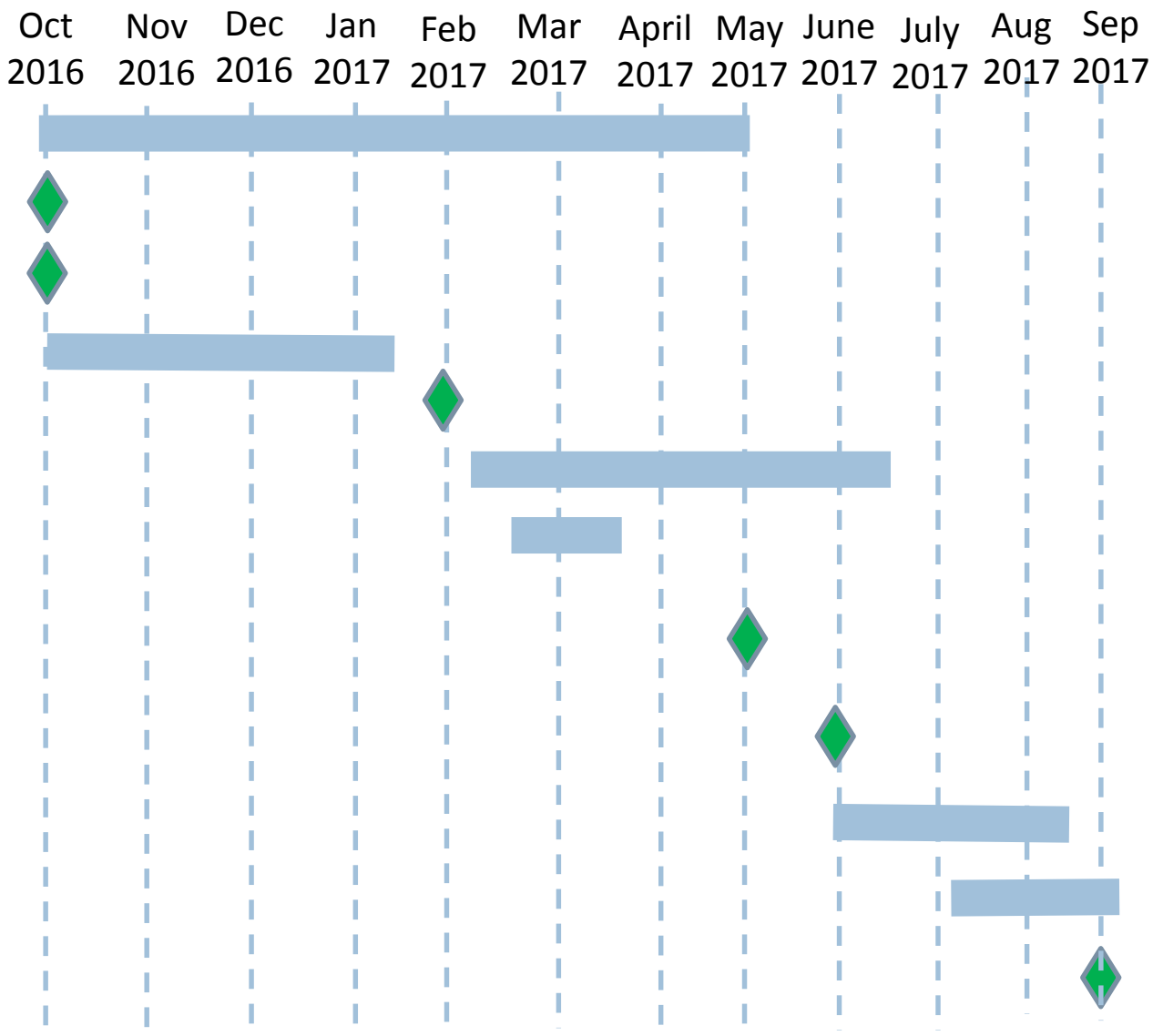
- Workforce Development
  - Seed industry with future innovators and engineers with real-world experience in advanced vehicle technologies
- Demonstration of energy-efficient powertrains, alternative fuels and innovative technologies and increasing transportation energy efficiency
- Develop and execute a safe, efficient and fair competition (ANL Ideology)
- Ensure the technical integrity of AVTCs, aligning with industry standards

Project Approach

- **Design and execute North America's premier collegiate Advanced Vehicle Technology Competition program**
  - Replicates real-world, hands-on, production-intent automotive industry experience in an academic environment, spur innovation and enhance education experience
  - Follows multi-year Vehicle Development Process (VDP) modeled after auto industry
  - Utilizes industry-leading engineering tools, methodologies and practices
  - Provides comprehensive automotive engineering education, training, and mentoring, matching students with subject matter experts from multiple areas of industry
- **Addressing Technical Barriers**
  - Enable teams to develop their vehicles with limited university resources by establishing a 30+ sponsor network providing $88M of support to teams
  - Model Based Design Curriculum and Applied Auto Engineering Curriculum projects to spread educational reach to larger academic community
  - Business program evolved into Project Management to equip teams/students for engineering project management and sponsor development
- **Integration with other VT programs:**
  - Clean Cities University Workforce Development Program (funds ~114 interns/yr.)
  - Other DOE programs (M&S, Vehicle Systems) – secured subject mater experts (SMEs) and judges to participate in workshops, competition and score reports and team deliverables

Milestones

Task
Year 3 Execution: Academic 2016/2017
Y3 Rules Released
Y3 Fall Workshop (MathWorks - Boston)
Y3 Fall Semester Team Deliverables
Y3 Winter Workshop (NXP – Austin)
Y3 Spring Semester Team Deliverables
Safety/Technical Team Inspections
Y3 Competition Finals (GM Milford Proving Ground – Detroit; DOE HQ – Washington, DC)
Y3 Competition Debrief
Y4 Internal Deep Dives/Planning
Y4 Rules Development
Y4 Faculty Advisory Board Meeting



Project Accomplishments & Progress: Vehicle Integration, Safety, and Testing in Year 3

Vehicle Integration Complete

- Team-built HV batteries commissioned
- 90% of teams were 100% integrated

Multiple Vehicle Safety Inspections Complete

- May 2016 (Y2): 13/16 teams passed
- March 2017 (Y3): mid-year pre-inspection
- May 2017 (Y3): 14/16 teams passed

Successful Vehicle Testing During Y3 Competition (GM Milford Proving Ground)

- 13 of 16 vehicles participated in testing events
- 10 of 16 vehicles demonstrated the capability to run as intended
- 10 of 16 vehicles attempted Emissions and Energy Consumption event
  - (4 teams completed this event)

Vehicle Test	Winner	Team
0-60 MPH Acceleration	5.73 sec	UT
50-70 MPH Acceleration	2.83 sec	UT
60-0 MPH Braking	121 ft	ERAU
Lateral Acceleration	0.979 g	ERAU
UF-Weighted Energy Consumption	604 Wh/km	OSU

Accomplishments/Progress: Y4 Vehicle Development

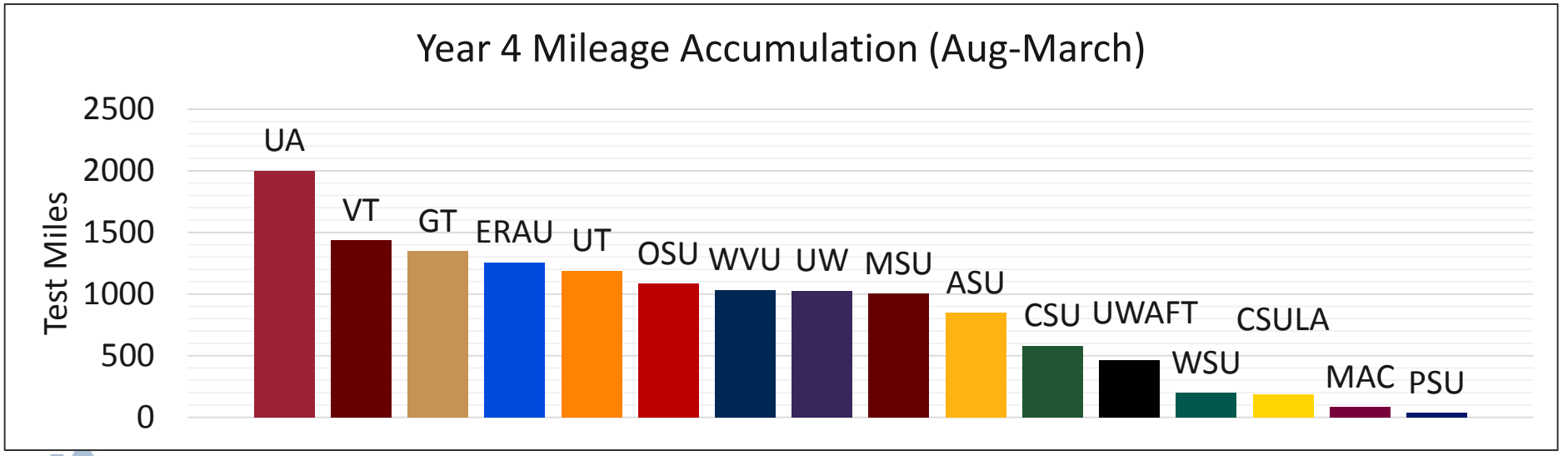
Vehicle Testing Glidepath Established for Teams

	Jan 2018	Feb 2018	March 2018
Mileage accumulation	100 mi	500 mi	1000 mi
Continuous endurance drive	50 mi	100 mi	200 mi

Extensive Vehicle Development Conducted at University Facilities

- Total mileage accumulation for all EcoCAR teams in Year 4: **13,764 miles**
- Teams that met mileage accumulation goals: **9 of 16 teams**
- Teams that met endurance drive goals: **9 of 16 teams**

As of March 28



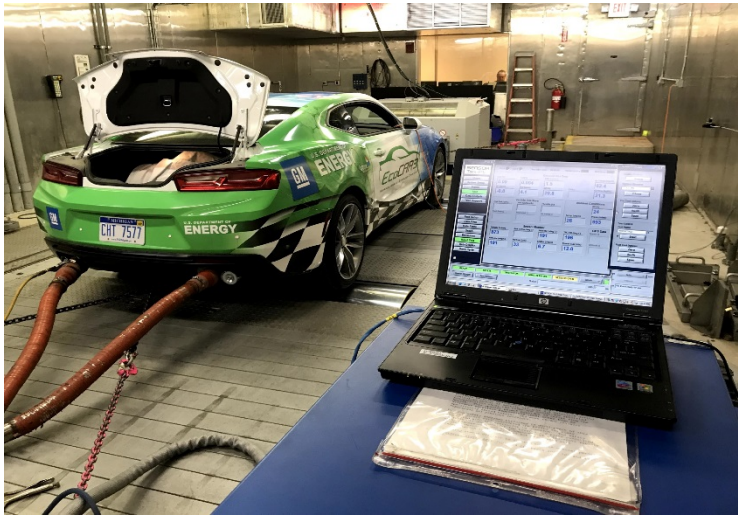
Accomplishments/Progress: Y4 Emissions Testing and Development

Emissions Testing Workshop Successfully Conducted at TRC

- Chassis dynamometer and laboratory grade emissions bench for emissions tuning
- 15 of 16 schools participated, each logging at least 8 hours of test time
  - 12 teams demonstrated capability to run as intended
- ~150 total hours of testing performed

Vehicle Safety Inspections Completed Prior to Testing

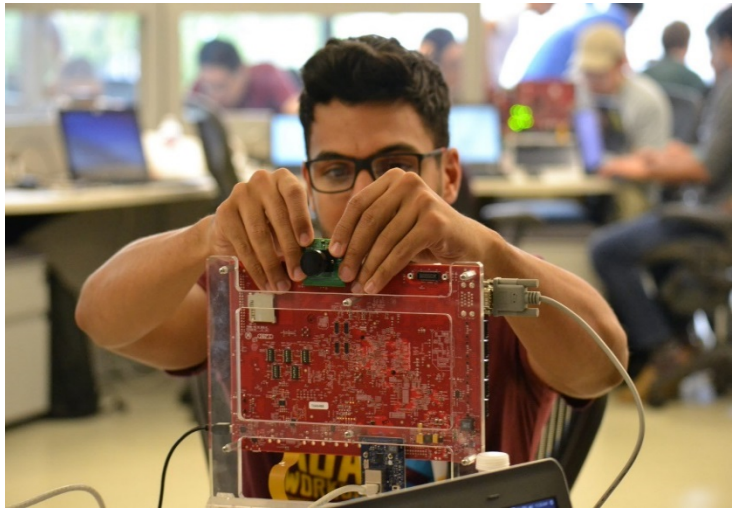
- All teams passed safety inspection for dyno testing



Accomplishments/Progress: Advanced Driver Assistance Systems

New in EcoCAR 3: ADAS Activity

- Teams use combination of vision and radar systems and sensor fusion methods
- Goal: Object detection and tracking, range and range-rate estimation



Incremental ADAS System Development

- May 2017: vision systems functioning on test rig (agnostic of competition vehicle)
- Nov 2017: ADAS workshop to train 60+ students
- Feb 2018: Full ADAS system permanently integrated in competition vehicle
- May 2018: on-vehicle ADAS system demonstration

ADAS Activities Gradually Ramped in During EC3

- Increased emphasis in future competition series

Accomplishments/Progress: Innovation

Major Innovation Initiative added in EcoCAR 3 in partnership with NSF

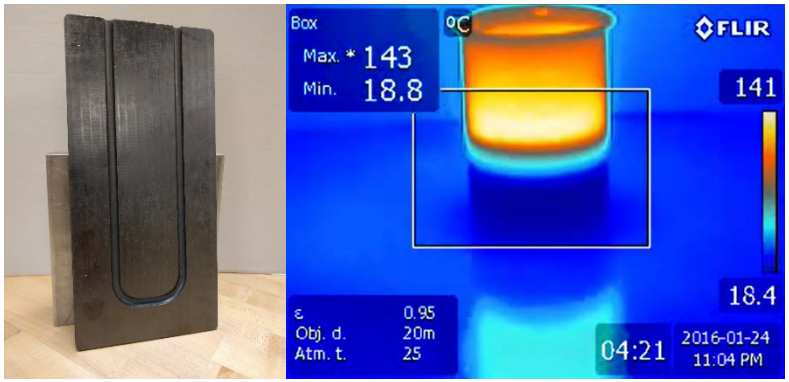
- Designed to spur R&D development at universities on topic of their choosing
- Each year, teams can continue with prior topic or select new one
- Significant support from NSF

Allows team to pursue high-risk topics away from critical path

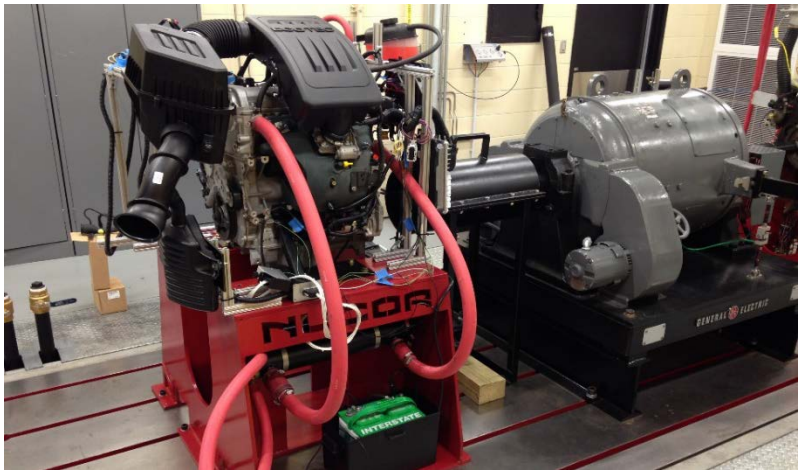
- Advances research in topics beyond hybrid system integration
- Embraces diversity of university backgrounds

Wide breadth of topics:

- V2X-based PHEV powertrain control
- EcoRouting for PHEVs
- Real-time cloud-based efficiency optimizations
- Additive manufacturing of mounts/driveshafts



Embry Riddle: Battery cooling plate using phase change composite material



Alabama: HCCI/SI E85 engine dyno cell

Accomplishments/Progress: Project Management and Communications Programs

Project Management Program:

- 16 Project Managers funded for FY16-18 (every team)
- Training provided to PMs to execute role
  - Manage/execute project schedule, timeline management, risk management, fundraising, budgeting and purchasing efforts
  - PM track training brought in-house to competition organizing team (no longer need to outsource trainers)
  - EcoCAR experience qualifies PMs to pursue CAPM certification
- 18 papers published by PMs in FY16-17

Communications Program:

- Program is a fully integrated multi-disciplinary aspect, and has been successfully operating for 8 years
- Each team has funded Communications Manager (CM)
- Professional Development Training provided to CMs to execute roles includes:
  - Media relations and interviewing, video production, strategic social media, website development, personal branding, recruitment tools, educational and influencer campaigns

Accomplishments/Progress:
STEM Outreach & Community Involvement

- Partnership with National Science Foundation to support diversity
  - Diversity in Engineering Award to encourage diversity among EcoCAR teams, youth
- **75** Middle & High School STEM events in Y3 reaching more than 10,000 students
- More than **90** community, campus, consumer, influencer, and professional organization outreach events in Y3
- **333** Total Youth Events in 3 years – reaching more than 10,000 students
- **635** Total Community Events in 3 years – reaching more than 15,000 individuals
- Expanded reach of program

Accomplishments/Progress: Media/PR

- 19.1 million media impressions
- 245 PR Newswire placements – 88.7 million impressions
- 1,073 BrandPoint placements – 143.2 million impressions
- Total Impressions for Y3: **251 million**
- 15,621 social engagements

Collaboration: Universities and Program Sponsors

Arizona State University
Cal State, Los Angeles
Colorado State University
Embry-Riddle Aeronautical University
Georgia Tech
McMaster University
Mississippi State University
The Ohio State University
Penn State University
University of Tennessee, Knoxville
University of Alabama
University of Washington
University of Waterloo
Virginia Tech
Wayne State University
West Virginia

Headline

U.S. DEPARTMENT OF ENERGY, GM

Visionary

MathWorks, NSF, California Environmental Protection Agency Air Resources Board, NXP, Clean Cities U.S. Department of Energy

Leadership

AVL, BOSCH Invented for life, ETAS, PACCAR, dSPACE

Sustaining

Snap-on, SIEMENS, GKN, TRC

Supporter

DENSO, CHAMPLAIN CABLE, WOODWARD, PROTERRA, RICARDO

Contributor

Mentor Automotive, New Eagle, tesa great to work with, VECTOR, DELPHI Foundation, Em empowering, EPRI ELECTRIC POWER RESEARCH INSTITUTE, A123 SYSTEMS, FLEXTRONICS

Overall Impact

- Seeded the industry with more than 25,000 graduates since 1988
- AVTC graduates are better prepared to contribute to the automotive industry
  - 85% of graduates go to work in the automotive industry
    - *Key contributors to products such as Chevy Volt/Bolt, Nissan Leaf, Tesla S Model, etc.*
  - 53% of GM-hired AVTC alumni have credit for at least one piece of protected intellectual property within two years of working in the company
- Diverse fleet of student-built prototype vehicles
  - Provides valuable data for academic research, publications, and student education
- Strong collaboration of more than 30 government and industry sponsors
  - Highly leveraged support from outside sponsors, expands R&D, scope and educational reach

Summary

The AVTC program is successfully addressing the following barriers:

- Lack of trained engineers and scientists
  - Over 25 years, AVTCs have seeded the automotive industry with 25,000+ engineers, business leaders and communicators who are making significant contributions to the industry immediately upon entry
  - Provides students a real-world, hands-on educational experience using latest auto industry tools, methods, and best practices to better prepare them for future careers as leaders of the automotive industry
- Lack of advanced vehicle technology curricula
  - Program provides automotive engineering education, training, and mentoring, matching students with subject matter experts from multiple areas of industry
  - Program drives teams to create new multi-disciplinary curricula at their university focusing on systems-level engineering
  - Model Based Design Curriculum Project provides in-depth modules across the academic community and public to teach the fundamentals of hybrid vehicle powertrain modeling
  - Applied Automotive Engineering Curriculum project provides several short modules - each provide basic 'startup' knowledge for automotive principles

Unique collaboration of government, industry and academia

- Demonstrates the benefits of sustainable vehicle solutions to address our current energy and transportation challenges

Questions?

EcoCAR3
Advanced Vehicle Technology Competition

Technical Back-Up Slides

Team Publications

Team	Author First	Author Last	FY	Paper Title	Conference/Journal Name
ASU	Mohammad	Alzorgan	FY17	Forward-Looking Traffic-Aware Cooperative Adaptive Speed and Battery Control System (CASBC)	Transactions on Vehicular Technology
ASU	Joshua	Carroll	FY16	Active Thermal Management within Electric and Hybrid Electric Vehicles	SAE PFL 2016
ASU	Mohammad	Alzorgan	FY16	Look-ahead information Based Optimization Strategy	SAE PFL 2016
ASU	Sushil	Kumar	FY16	Vehicle Plant Model and Supervisory Control Development for a Parallel Pre-Trans Plug-In Hybrid Electric Vehicle	SAE World Congress 2016
ASU	Kumail	Selani	FY16	EcoCAR 3 Advanced vehicle Technology Competition and Its Impact on ASU	Journal of Behavioral and Applied Management
CSU	Jamison	Bair	FY17	Introduction and Application of Lean Manufacturing Techniques in Mechanical Engineering Senior Deiscgn Practicum	2017 Annual Conference & Exposition
CSU	Vipin Kumar	Kukkala	FY17	Uncertainty Analysis and Propagation for an Auxiliary Power Module	Transportation Electrification Conference and Expo
CSU	Zachary	Asher	FY17	Prediction Error Applied to Hybrid Electric Vehicle Optimal Fuel Economy	Transactions on Control Systems Technology
CSU	David	Baker	FY17	Investigation of Vehicle Speed Prediction from Neural Network Fit of Real World Driving Data for Improved Engine On/Off Control of the EcoCAR3 Hybrid Camaro	World Congress 2017
CSU	Zachary	Asher	FY17	The Importance of HEV Fuel Economy and Two Research Gaps Preventing Real World Implementation of Optimal Energy Management	Symposium on International Automotive Technology 2017
CSU	Clinton	Knackstedt	FY16	Reducing Effective Vehicle Emissions Through the Integration of a Carbon Capture and Sequestration System in the CSU EcoCAR Vehicle	SAE PFL 2016
CSU	Eric	Jambor	FY16	Weight Reduction Through the Design and Manufacturing of Composite Half-Shafts for the EcoCAR 3	SAE World Congress 2016
CSU	Vipin	Kukkala	FY16	Priority-based Multi-level Monitoring of Signal Integrity in a Distributed Powertrain Control System	Elsevier Journal
CSULA	Khashayar	Olia	FY16	Controls Systems Development Application via Parallel Post Rear Wheel Drive	SAE World Congress 2016
ERAU	Andre	Napier	FY17	Electrification of a plug-in hybrid Chevrolet Camaro, a System Engineering Approach	Master's Thesis
ERAU	Thomas	Gorgia	FY17	Supervisory Controller to Reduce Utility Factor Weighted Criteria Emissions for A PHEV	International Journal of Alternative Powertrains
ERAU	Kevin	Cwiok	FY16	Investigation Of The Effectiveness Of Carbon Fiber Additives In A Phase-Change Material Coldplate For Hybrid-Electric Vehicle Battery Thermal Management	ASME IMECE 2016
ERAU	Jared	Nordman	FY16	Engineering Project Management: Implementing New Techniques for the EcoCAR 3 Competition Team at ERAU	ASEM 2016 Annual Conference
GT	Greg	Chipman	FY17	Adapting Vertically Integrated Projects to University Team Competitions	IMECE 2017
GT	Lee	Sargent	FY17	Commissioning of a Motor-Generator Unit	Transportation Electrification Conference and Expo
GT	Doug	Cox	FY16	Selection of a P3 parallel hybrid electric vehicle architecture for the EcoCAR 3 competition	SAE World Congress 2016
GT	Sriganesh	Sriram	FY16	Modeling and Control of Power-Split Powertrains: Examining the Influence of Drive-Shaft Compliance	IEEE
GT	Greg	Chipman	FY16	Educating Chemical Engineers with Interest in the Automotive Industry	AiChE 2016 Annual Conference

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MAC	Mackenzie	Wootton	FY17	Optimal performance of a full scale li-ion battery and li-ion capacitor hybrid energy storage system for a plug-in hybrid vehicle	Energy Conversion Congress and Exposition (ECCE)
MAC	Ephrem	Chemali	FY17	On the concept of a novel Reconfigurable Multi-Source Inverter	Transportation Electrification Conference and Expo (ITEC)
MSU	Myles	Black	FY17	Decision-Analysis Technique Applied in an Advanced Vehicle Technology Competition	4th International Conference on Industrial Engineering and Applications
MSU	Alex	Gibson	FY17	Vision Processing Methods for Advanced Driver Assistance Systems	International Conference of Automotive Engineering
MSU	John	Corn	FY17	Torque Blending Control Strategy for Series-Parallel Plug-in Hybrid Electric Vehicle Architecture	2017 International Powertrains, Fuels & Lubricants Meeting
MSU	John	Corn	FY16	A Comparison of the Mississippi State University EcoCAR 3 Team Vehicle Architecture Motor Control Strategies	SAE World Congress 2016
MSU	Stephen	Hayes	FY16	Applying IE to an Organization's Biggest Asset—Its People	IISE 2016 Annual Conference
OSU	Simon	Trask	FY17	System Diagnosis and Dault Mitigation Strategy Development for an Automated Manual Transmission Using Structural Analysis	2017 Dynamic Systems and Control Conference
OSU	Guido	Guercioni	FY17	Gearshift Control for Hybrid Powertrains with AMTs	2017 International Conference of Electrical and Electronic Technologies for Automotive
OSU	Dennis	Kibalama	FY17	Testing and Validation of a Belted Alternator System for a Post-Transmission Parallel PHEV for the EcoCAR 3 Competition	World Congress 2017
OSU	Arjunn	Khanna	FY16	Model and Controls Development of a Post-Transmission PHEV for the EcoCAR 3 Competition	SAE World Congress 2016
OSU	Sam	Yacinthe	FY16	Development of the Design of a Plug-in Hybrid-Electric Vehicle for the EcoCAR 3 Competition	SAE World Congress 2016
PSU	Hugo	McMenamin	FY17	Energy Consumption Strategy of a Parallel Pre-Transmission Plug-in Hybrid Electric Passenger Performance Vehicle	2017 Conference on Smart Materials, Adaptive Structures and Intelligent Systems
PSU	Dule	Shu	FY17	A Sum-of-Squares Polynomial Approach for Road Anomaly Detection Using Vehicle Sensor Measurements	2017 Dynamic Systems and Control Conference
PSU	Hugo	McMenamin	FY16	Design Of A Hybrid Electric Vehicle Driver Model To Simulate Multiple State Dependence	ASME SMASIS 2016
PSU	Dave	Chatterpaul	FY16	Improving Internal Communication in an Organization Using Project Management Techniques	PMI Project Management Journal
UA	Kaylie	Crosby	FY16	Implementation of Onboarding Procedure Will Lead to Increase in Team Motivation and involvement	ASEM 2016 Annual Conference
UT	Liu	Liu	FY17	End-to-End Binary Representation Learning Via Direct Binary Embedding	Department Library
UT	Eli	Allen	FY17	Control System Operation of the UTK EcoCAR 3 HEV	IDETC/CIE 2017
UT	Tianxiang	Chen	FY16	A Novel Method for the Detection of Front Vehicle Turn Signals	SAE World Congress 2016
UT	Adian	Cook	FY16	Software ECU Validation and Hybrid Supervisory Control Refinement via Real-Time Engine Dynamometer Data	SAE World Congress 2016

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UW	Aman	Kalia	FY17	Development of Optimal Control Strategy for a Plug-in Series Hybrid Electric Vehicle with an On-Board Engine-Generator System for Overall Fuel Economy Improvement and Reduction in Tailpipe Emissions	Internal Combustion Engine Fall Technical Conference
UW	James	Goin	FY17	Predictive Generator Control of a Series Plug-in Hybrid Vehicle	2017 Conference on Smart Materials, Adaptive Structures and Intelligent Systems
UW	Graham	Arnold	FY17	Simulation of Advanced Regenerative Braking Strategies in a Series Plug-in Hybrid Electric Vehicle	Society of Automotive Engineers (SAE) Technical Papers - Non Event
UW	Brian	Magnuson	FY16	Improving Vehicle Fuel Economy through Driver Prediction	SAE World Congress 2016
UW	Nathaniel	Steinbock	FY16	Active Torque Vectoring In High Speed Lane Change Maneuvers	ASME IMECE 2016
UWAFT	Radhika	Kartha	FY17	Comparative Study of the Organizational Structure of Engineering Student Teams and Team Effectiveness	CEEA/ACEG 2017 Conference
UWAFT	John	Catton	FY17	Comparative Safety Risk and the Use of Repurposed EV Batteries for Stationary Energy Storage	2017 IEEE International Conference on Smart Energy Grid Engineering (SEGE)
UWAFT	John	Catton	FY17	Extended Range Electric Vehicle Powertrain Simulation, and Comparison with Consideration of Fuel Cell and Metal-Air Battery	World Congress 2017
UWAFT	Patrick	Ellsworth	FY16	Control Analysis for Efficiency Optimization of a High Performance Hybrid Electric Vehicle with Both Pre and Post Transmission Motors	SAE World Congress 2016
UWAFT	Paul	McInnis	FY16	Control Analysis for Efficiency Optimization of a High Performance Hybrid Electric Vehicle with Both Pre and Post Transmission Motors	SAE World Congress 2016
VT	Hrusheekesh	Warpe	FY17	EcoRouting Strategy using Variable Acceleration Rate Synthesis Methodology	Society of Automotive Engineers (SAE) Technical Papers - Non Event
VT	Eduardo	Marquez	FY17	Simulation and Bench Testing of a GM 5.3L V8 Engine	World Congress 2017
VT	Andres	Coello	FY17	Implementation of Hands-On Supplement Projects in the On-Boarding Process of a Senior Design Team	Society of Automotive Engineers (SAE) Technical Papers - Non Event
VT	Samuel	Reinsel	FY17	Drive Quality Assessment of Stock vehicles for EcoCAR Benchmarking	Society of Automotive Engineers (SAE) Technical Papers - Non Event
VT	Eduardo	Marquez	FY16	Control Strategy Development for Parallel Plug-in Hybrid Electric Vehicle Using Fuzzy Control Logic	SAE PFL 2016
VT	Pramit	Baul	FY16	EcoRouting for Performance Plug-in Hybrid Electric Vehicles	SAE PFL 2016
VT	David	Mackanic	FY16	Development of a Software-In-The-Loop Model for a Parallel Plug-In Hybrid Electric Vehicle	SAE World Congress 2016
VT	William	Dvorkin	FY16	Financial Viability Analysis Of An Engineering Design Team	ASEM 2016 Annual Conference

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WSU	Miriam	Di Russo	FY17	Development of the Hybrid Supervisory Controller for a Pre-Transmission Hybrid Electric Vehicle for Year 3 of the EcoCAR3 Competition	WAUTO116 Powertrain/Propulsion
WSU	Juan	Sebastian Briones	FY16	Offline Electro-hydraulic Clutch Bench Testing Alternatives for a Pre-Transmission Parallel Hybrid Powertrain	SAE PFL 2016
WSU	Miriam	Di Russo	FY16	Control Development for an Engine-disconnect Clutch in a Pre-Transmission Parallel Hybrid Electric Vehicle	SAE PFL 2016
WSU	Kevin	L. Snyder	FY16	Advancement and Validation of a Plug-In Hybrid Electric Vehicle Plant Model	SAE World Congress 2016
WSU	Miriam	Di Russo	FY16	WSU EcoCAR 3 Year 1 Final Technical Report: Developing Modeling, Simulation, and Control of a Pre-Transmission Parallel E85 PHEV	SAE World Congress 2016
WVU	Hadi	Kazemi	FY17	Predictive AECMS by Utilization of Intelligent Transportation Systems for Hybrid Electric Vehicle Powertrain Control	IEEE Transactions on Intelligent Vehicles
WVU	Hadi	Kazemi	FY16	Utilizing Situational Awareness for Efficient Control of Powertrain in Parallel Hybrid Electric Vehicles	IEEE ICUWB 2015
WVU	Justin	Brumley	FY16	Exploration of Energy Consumption Through Diverse Cooling Methods	ASME IMECE 2016